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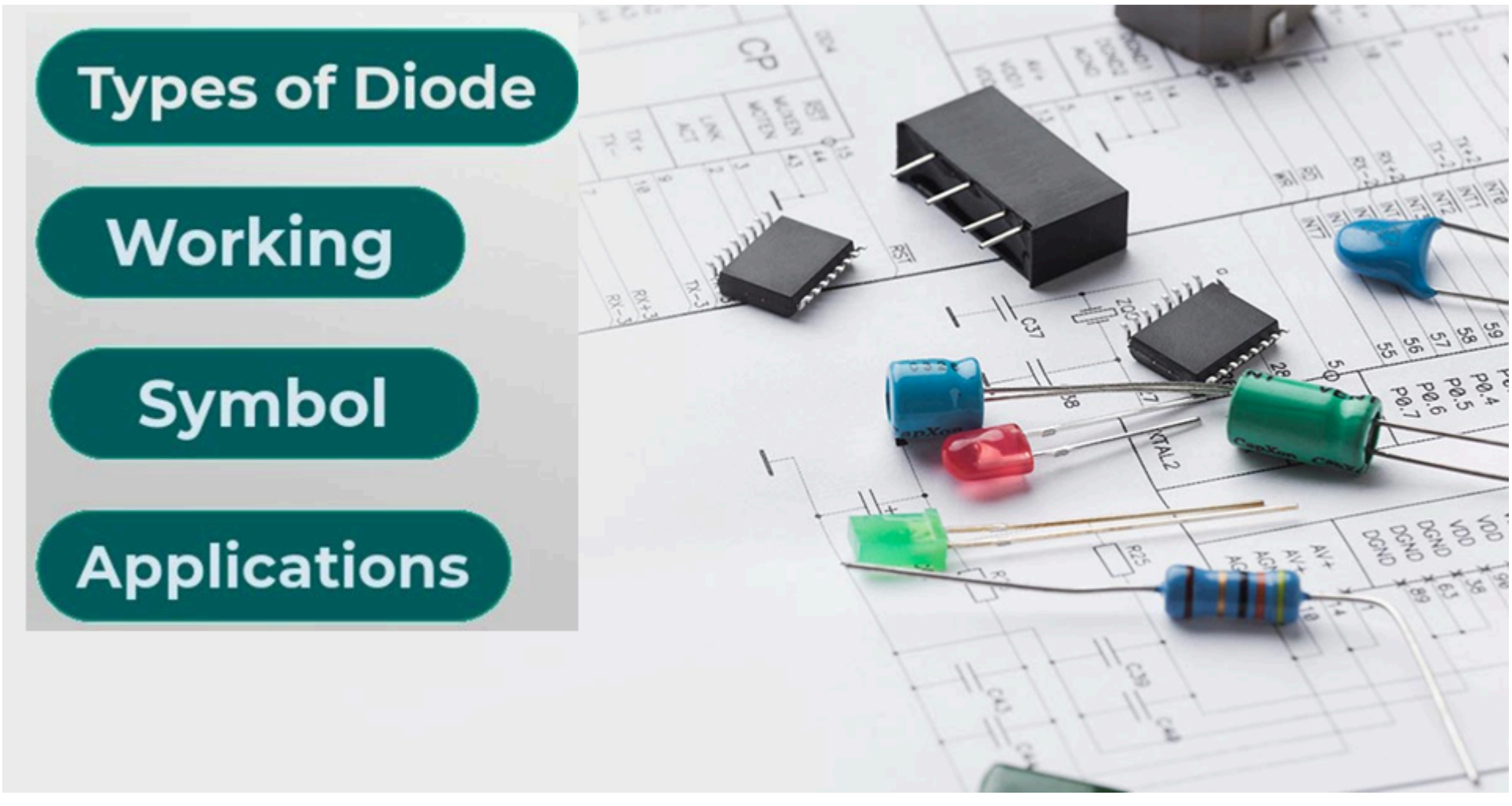
DIFFERENT TYPES OF DIODES AND THEIR USES

07/19/25 10:06:00 PM



1. Introduction

Diodes are two-terminal semiconductor devices that conduct current primarily in one direction, acting as electrical “check valves.” Their behavior depends on the P–N junction properties, doping concentrations and device geometry. Key parameters include forward voltage drop (VF), reverse breakdown voltage (VR) and switching characteristics such as reverse recovery time (trr) and junction capacitance (Cj). A deep understanding of these factors ensures optimal diode selection across power conversion, signal processing, protection and optoelectronic applications.

2. Key Electrical Parameters

- VF (Forward Voltage Drop): Voltage across diode in forward bias, typically 0.7 V for silicon PN, 0.15–0.45 V for Schottky.
- VR (Reverse Breakdown Voltage): The reverse-bias voltage at which avalanche or Zener breakdown occurs.
- IR (Reverse Leakage Current): Small current flowing under reverse bias, varies from nA in precision types to mA in Schottkys.
- trr (Reverse Recovery Time): Time for stored charge to clear when switching from forward to reverse conduction.
- Cj (Junction Capacitance): Capacitance of the depletion region under reverse bias, critical in RF applications.

3. Diode Types and Technical Details

3.1 Rectifier Diode

A high-current P–N junction diode with a large junction area to handle 1 A–500 A and VR ratings from 50 V to >1000 V. trr is in the microsecond–millisecond range, making it unsuitable for high-frequency switching. Predominant use is AC→DC conversion in bridge rectifiers, battery chargers and power supplies.

Specifications:

Parameter	Range
VRRM	50–1200 V
IF(AV)	1–500 A

Parameter	Range
trr	1–50 μs
VF	0.7–1.1 V

3.2 Small Signal Diode

A low-current (~<100 mA), low-capacitance PN junction with trr <50 ns and VR up to 200 V. Junction area is minimal to reduce stored charge. Ideal for RF detectors, high-speed switching and ESD protection in digital and RF circuits.

Specifications:

Parameter	Range
VR	50–200 V
IF(peak)	50–200 mA
trr	<50 ns
Cj	<2 pF

3.3 Schottky Diode

A metal-semiconductor junction device with no P–N depletion capacitance, yielding VF ≈0.15–0.45 V and ultrafast switching (trr <5 ns). Reverse leakage (IR) is higher than PN diodes, and VR is limited to 20–200 V. Widely used in SMPS, reverse-current blocking for photovoltaic arrays, and high-frequency rectification.

Specifications:

Parameter	Range
VR	20–200 V
IF	0.1–30 A
trr	<5 ns
VF	0.15–0.45 V

3.4 Zener Diode

A heavily doped PN device designed to enter controlled breakdown at VZ from 2.4 V to 200 V. In reverse bias beyond VZ, it maintains a nearly constant voltage, serving as shunt regulators, voltage references and overvoltage protectors. trr is moderate (tens of ns) and IR in breakdown can be tens of μA to hundreds of mA.

Specifications:

Parameter	Range
VZ	2.4–200 V
IZ	1–200 mA
rz	5–50 Ω
VF	0.7 V

3.5 Avalanche Diode

Similar to Zener but optimized for high-energy, high-voltage contexts (VR >6 V). Lightly doped to create a wide depletion region, requiring higher VR for breakdown. Exhibits fast recovery and can absorb large surge energy, making it ideal for TVS elements and surge suppressors.

Specifications:

Parameter	Range
VR	6–800 V
IPPM (Pulse)	5–100 A
tp(max)	<1 μs

3.6 Transient Voltage Suppression (TVS) Diode

A specialized avalanche diode engineered to clamp voltage spikes in <1 μs and divert kiloamps of transient current. Available in unidirectional and bidirectional forms, TVS diodes protect I/O lines, power rails and automotive electronics from ESD, lightning and inductive switching surges.

Specifications:

Parameter	Range
VRWM	5–600 V
IPP	10–20 kA (10/1000 μs)
VC	VRWM + 10–30 V

3.7 Light Emitting Diode (LED)

A direct-bandgap PN device that emits photons when forward biased. Emission wavelength depends on semiconductor alloy bandgap, ranging from IR through visible to UV. VF ranges from 1.8 V (infrared) to 3.5 V (blue/UV). Used in indicators, displays, solid-state lighting, traffic signals and backlighting.

Specifications:

Parameter	Range
VF	1.8–3.5 V
IF	1–100 mA
λ	460–940 nm

3.8 Photodiode

A PN or PIN device operated in reverse bias, converting incident photons into photocurrent (IP ∝ light intensity). PIN structures are favored for lower Cj and faster response (<1 ns), while standard PN photodiodes suit low-speed sensing. Applications include optical communication, photometry and solar energy harvesting.

Specifications:

Parameter	Range
VR	5–50 V
Responsivity	0.2–0.7 A/W
tr	<1 ns (PIN)
Cj	<1 pF

3.9 Laser Diode

A PIN-junction device with reflective facets forming a resonant cavity. Electrons and holes recombine in the intrinsic region to produce coherent laser emission. Emission spans 650 nm (red) to 1550 nm (telecom). VF is 1.5–3 V; typical IF is 10–200 mA. Used in fiber optics, barcode scanners, printing and medical instruments.

Specifications:

Parameter	Range
VF	1.5–3 V
IF	10–200 mA
λ	650–1550 nm
Pout	1 mW–100 mW

3.10 Varactor (Varicap) Diode

A reverse-biased PN device used as a voltage-controlled capacitor. Cj varies from a few pF to tens of pF as VR changes from 0 to 30 V. Employed in VCOs, PLLs and tunable RF filters in communication and radar systems.

Specifications:

Parameter	Range
VR	0–30 V
Cj	2–50 pF
Q-factor	200–1000 (@1 GHz)

3.11 PIN Diode

Features a wide intrinsic region between P and N layers, reducing Cj and extending carrier lifetime. Supports RF switches, attenuators and high-power photodiodes. Operates over GHz frequencies with low insertion loss and high isolation.

Specifications:

Parameter	Range
VR	5–100 V
tr	<1 ns
Cj	<0.5 pF

3.12 Tunnel (Esaki) Diode

A heavily doped PN device exploiting quantum tunneling. Exhibits negative resistance between 0.1–0.7 V, enabling high-frequency oscillators and microwave amplifiers up to tens of GHz. VF on the leading edge is low (~0.3 V), with peak current densities of several kA/cm².

Specifications:

Parameter	Range
Vp	0.1–0.7 V
Ip	1–100 mA
fosc	10–100 GHz

3.13 Gunn Diode

A bulk GaAs device without a P–N junction, utilizing transferred-electron (Gunn) effect to generate microwave oscillations (2–100 GHz). VF is typically 2–4 V, IF is 20–200 mA. Used in police radar, microwave transmitters and local oscillators.

Specifications:

Parameter	Range
Vop	2–4 V
Iop	20–200 mA
fosc	2–100 GHz

3.14 Backward Diode

A variant of tunnel diode optimized for reverse conduction at very low voltages (0.1–0.6 V). Offers zero-bias detection of RF signals and small-signal rectification with minimal noise. Used in microwave mixers and detectors.

Specifications:

Parameter	Range
VR(th)	0.1–0.6 V
IR	<1 μA at 1 V

3.15 Step Recovery (Snap-off) Diode

Stores charge in forward bias and releases it abruptly upon reverse bias, generating very fast transition pulses. Snap time is <10 ps, cutoff frequencies up to 300 GHz. Employed in pulse generators, frequency multipliers and high-speed digital circuits.

Specifications:

Parameter	Range
trr	<10 ps
fmax	200–300 GHz

3.16 Gold-Doped Diode

Incorporates gold atoms to shorten carrier lifetime, dramatically speeding recovery. Used in ultra-fast switching logic, high-frequency RF switches and gated photodetectors requiring sub-nanosecond response.

Specifications:

Parameter	Range
trr	<1 ns
VF	0.7 V

3.17 Super Barrier Diode

Combines MOS–PN architecture to achieve low VF (~0.45 V) and low IR like PN diodes, with fast switching comparable to Schottkys. Ideal for high-efficiency power supplies and synchronous rectifiers in renewable energy inverters.

Specifications:

Parameter	Range
VR	20–1000 V
VF	~0.45 V
IR	<1 μA

3.18 Shockley Diode

A four-layer PNPN device without gate control, functioning as a two-terminal thyristor. Turns on when forward voltage exceeds 0.7–1.2 V and latches until current falls below holding level. Used in relaxation oscillators and trigger circuits for SCRs.

Specifications:

Parameter	Range
VON	0.7–1.2 V
IH	1–50 mA

3.19 Vacuum Diode

An electrode pair in a vacuum tube where the cathode emits thermionic electrons to anode when forward biased. Handles very high voltages and powers; largely superseded but still used in specialized high-frequency and high-power RF applications such as broadcast transmitters and X-ray tubes.

Specifications:

Parameter	Range
Vop	Up to 50 kV
Iop	Up to several A

3.20 Peltier (Thermal) Diode

Relies on Peltier effect at PN junction—heating or cooling upon current flow. ΔT of a few K at currents of 0.1–5 A. Used in compact thermoelectric coolers for electronics hotspots and medical thermoregulation devices.

Specifications:

Parameter	Range
Iop	0.1–5 A
ΔT	5–20 K

4. Summary of Key Diode Characteristics

Type	VF (V)	VR (V)	IF/IPP	trr	Main Applications
Rectifier	0.7–1.1	50–1200	1–500 A	1–50 μs	Power supplies, chargers
Small Signal	0.7	50–200	<200 mA	<50 ns	RF detection, high-speed switch
Schottky	0.15–0.45	20–200	0.1–30 A	<5 ns	SMPS, PV blocking
Zener	0.7	2.4–200	1–200 mA	10–100 ns	Voltage reference/regulation
Avalanche/TVS	0.7	6–800/5–600	5–100 A/10–20 kA	<1 μs	Surge protection
LED	1.8–3.5	5–30	1–100 mA	—	Lighting, indicators
Photodiode (PIN)	—	5–50	—	<1 ns	Optical sensors, telecom
Laser	1.5–3	5–20	10–200 mA	—	Fiber-optics, medical, printing
Varactor	—	0–30	—	—	VCO, PLL, RF filtering
Tunnel	0.1–0.7	0.5–2	1–100 mA	—	Microwave oscillators
Gunn	2–4	—	20–200 mA	—	Radar, microwave sources
Backward	—	0.1–0.6	—	—	RF detection
Step Recovery	0.7	20–60	—	<10 ps	Pulse generation, frequency mult
Gold-Doped	0.7	20–60	—	<1 ns	Ultra-fast switching

Type	VF (V)	VR (V)	IF/IPP	trr	Main Applications
Super Barrier	~0.45	20–1000	—	<5 ns	Efficient rectification
Shockley	0.7–1.2	—	1–50 mA	—	Relaxation oscillators
Vacuum	—	up to 50 kV	up to A	—	High-power RF, X-ray
Peltier	—	—	0.1–5 A	—	Thermoelectric cooling

5. Storage, Maintenance & Safety

- Store diodes in dry, temperature-controlled environments to prevent moisture ingress and corrosion.
- Use ESD precautions for small-signal and optoelectronic diodes: grounded workstations, antistatic bags and wrist straps.
- Inspect hermetic packages for leaks in high-reliability applications.
- Verify VR and VF periodically with semiconductor curve tracers for drift in critical circuits.

6. Future Trends

- Wide-bandgap materials (SiC, GaN) pushing VR >10 kV, VF down to 0.4 V, and trr <1 ns.
- Integrated smart diodes with on-chip sensing for real-time thermal and current monitoring.
- Nano-engineered junctions achieving sub-100 ps switching for next-gen digital and microwave systems.
- Hybrid optoelectronic devices merging LED/laser and photodiode in single packages for compact LiDAR and bi-directional optical links.

7. Further Reading

- Design considerations for SiC Schottky diodes in EV onboard chargers.
- SPICE modeling of step recovery and tunnel diodes for RF PA design.
- Packaging techniques for high-power TVS arrays in industrial surge protection.
- Comparative analysis of PIN vs PIN-G481 photodiode arrays in 100 Gbps optical links.
- Thermal management strategies in stacked Peltier modules for microfluidic cooling.

Mastering the nuances of diode physics, materials and circuit integration empowers engineers to innovate across power electronics, communications, sensing and optoelectronics.

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